# The Analysis of Reactively Loaded Microstrip Antennas by Finite Difference Time Domain Modelling

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## ABSTRACT

In recent years much interest has been shown in the use of printed circuit antennas in mobile satellite and communications terminals at microwave frequencies. Although such antennas have many advantages in weight and profile size over more conventional reflector/horn configurations, they do, however, suffer from an inherently narrow bandwidth.

This paper examines a way of optimising the bandwidth of such antennas by an electronic tuning technique using a loaded probe mounted within the antenna structure, and shows the resulting far-field radiation patterns. Simulation Results from a two-dimensional Finite Difference Time Domain ( FDTD ) model for a rectangular microstrip antenna loaded with shorting pins will then be given, and compared to results obtained with an actual antenna.

It is hoped that this work will result in a design package for the analysis of microstrip patch antenna elements.

## INTRODUCTION

The microstrip patch antennas used in the following experiments consist of an electrically-thin, copper-clad substrate, with a conducting patch etched on one surface while the other is left as a ground plane. Thus, the structure resembles a thin, open-circuited resonant cavity whose losses are due mainly to radiation from the patch, but also to a lesser extent from both the conductor and dielectric.

The edges of the patch can be regarded as radiating apertures with the size of the aperture ( dependant upon the width of surface conductor and the thickness of dielectric ) determining the amount of radiation loss. However, radiation loss takes the form of both free-space radiation and substrate surface waves, with the latter becoming an increasing problem with increased dielectric thickness. On the other hand a narrow substrate results in less radiation and hence a higher Q factor. Therefore, typical values for the input VSWR bandwidth of a rectangular patch microstrip antenna are in the region of 1 - 4 % .

Various schemes to increase the bandwidth of the microstrip structure exist; such as the use of different conductor shapes or parasitic elements [1]. Other methods take a basic patch antenna and modify the field structures within the patch by the use of shorting pins between surface conductor and ground plane, or by the use of reactively loaded probes [2]. In this way certain resonant modes of the antenna can be suppressed whilst others may be excited, resulting in either increased input bandwidth or closer multiple resonances.

However, it should be noted that although these modifications may improve the input feed/antenna match over a wider frequency, this may result

in the formation of unsuitable far-field radiation pattern and/or no real increase in main beam gain. Another drawback might be the increase of cross-polar products, hence a compromise between input match and radiation fields may have to be sought.

## PROJECT OVERVIEW

The overall aim of the project is to develop a method of analysing microstrip antenna elements and arrays for use in mobile satellite and communication terminals. These antennas may have to be frequency adjustable and/or multi-resonant.

For instance, with the INMARSAT Standard-C satellite system, it was envisaged that a single, high Q patch could be used to cover the bands 1530-1545 MHz and 1626.5-1646.5 MHz - a basic circular polarised square patch design has an input bandwidth of greater than 20 MHz but does not produce a suitable match at both the required bands. Therefore basic dual feed, 'single' frequency, microstrip patches of the type previously used at Bristol University for satellite signal acquisition [3,4], would not be suitable, so a more complicated structure would be required.

## LOADED PROBE MICROSTRIP ANTENNA

The initial task was to prove that the use of a single, reactively loaded probe within a microstrip patch element could produce a suitable tuning capacity to give an improved broadside gain response. Methods of generating circular polarisation are to be dealt with at a later stage in the work, and are not included in this paper.

A series of tests were carried out on a rectangular microstrip patch antenna etched on a RT/Duroid substrate with a dielectric permittivity of 2.2 . The dimensions of the patch were chosen purely to fit the grid of the mathematical model to be described later in this paper, and not for any specific frequency requirement other than general operation in the L band.

The antenna consisted of a rectangular patch, 86.4 x 57.6 mm, etched onto a 1.6 mm thick board. Two probes were placed within the substrate and attached to SMA connectors on the ground plane; the positions of the feed and load probes are shown in Fig. 1. The feed point was chosen to give a relatively good input match and low excitation of modes giving rise to cross-polar radiation, while the load position was experimentally determined such as to not encourage cross-polar radiation and yet still maintaining a useful tuning operation.

In order to vary the reactive loading on the probe, a phase-shifter was attached to the loading port. This consisted of a hybrid coupler incorporating two varactor diodes connected to ground in the output arms, while the 'isolated' port remained open-circuited.

By variation of the bias voltage applied to the phase-shifter, the effective length of the open-circuit is either increased or decreased resulting in a change in the reactive load as seen by the antenna. On full bias the total phase shift, at the original antenna resonance frequency, was increased by approximately 130°.

### Results for loaded probe antenna

Measurement of the input feed/antenna match of the microstrip antenna revealed a VSWR of less than 1.1 for the unactivated phase shifter at the resonant frequency of 1674 MHz; the bandwidth ( for an input VSWR<2 ) being 23.3 MHz. Activation of the phase shifting network, giving a maximum loading of the antenna, moved the resonant frequency to 1708 MHz, with a corresponding VSWR of 1.33 and a bandwidth of 18.6 MHz.

Before activation of the phase-shifter, the VSWR at 1708 MHz had been 5.5; therefore, this improved match should have resulted in 2.8 dB more radiated power. Subsequent measurement of far-field radiation patterns gave an

improvement in broadside gain of 2.6 dB. However, the received power at this frequency was still 2 dB less than that achieved at the original lower frequency. By reduction of the loading at the probe an improvement in gain of 0.8 dB was obtained, although the resonant frequency of the antenna was now reduced to 1695 MHz. Thus, it can be seen that best input VSWR match of the antenna does not necessarily correspond to the best achievable signal strength.

The co-polar and cross-polar far-field radiation patterns for one of the orthogonal antenna planes at 1674 MHz ( without loading ) is shown in Fig. 2, while the equivalent plots at 1708 MHz ( phase-shifter operating with a loading below maximum ) are shown in Fig. 3.

It can be seen that the shapes of the two co-polar plots are very similar, indicating that there has been no major excitation of additional modes within the patch. The gain at the higher, tuned, frequency is 1 dB down on the level achieved at the lower frequency ( without loading ) rather than 4.4 dB as would be the case without the loading. Therefore, there has been a 3.4 dB improvement with the loaded antenna in the gain achieved 34 MHz above the original resonant frequency. In all cases the cross-polar radiation levels were more than 20 dB below their corresponding co-polar responses.

It can be seen that this simple method can be used to optimise signal strengths without causing any major change in radiation pattern shape. Further investigation is now being undertaken to determine the capability of such a method to tune circularly polarised microstrip patch elements.

## FINITE-DIFFERENCE TIME-DOMAIN MODELLING

The regularly shaped microstrip patch antennas ( e.g. rectangular, circular ) can be reasonably matched to a feed

transmission line using modal analysis of the structure [5,6]. However, the addition of shorting pins and reactively loaded probes, leading to excitation of non-standard resonances, requires a more general analysis technique.

Both finite-element and finite-difference techniques were considered, though a finite-difference model was initially chosen for evaluation.

The basic algorithms for the finite-difference solution of Maxwell's equations are given below :

$$\nabla \times \underline{H} = \sigma\underline{E} + \varepsilon( \Delta\underline{E}/\Delta t )   ( 1 )$$

$$\nabla \times \underline{E} = -\mu( \Delta\underline{H}/\Delta t )   ( 2 )$$

and described in [7] and [8].

The space surrounding the conducting elements is divided into cubic grids, with the grid meshes usually being concentrated at areas of major field changes, i.e. discontinuities within the structure. A signal (or signals) are applied to the model while the electric and magnetic fields are monitored as a function of time. After many iterations of the basic algorithm the simulation model will settle down to a steady-state condition. At this time the voltage and current at the feed point can be used to determine the impedance at that point.

## LOADED MICROSTRIP PATCH SIMULATION

Extensive work has been carried out at Bristol University on the modelling of enclosed microstrip discontinuities [9], and this is being extended to cover perfect absorbing boundaries for use in antenna work. However, for the analysis of shorted microstrip structures a slightly different approach was used that required a coarser and simpler grid, and hence less processing time.

The method used was only required to give a useful trend to the field resonances within a loaded patch structure over a limited bandwidth. It was therefore considered that only a two-dimensional finite-difference time-domain ( FDTD ) model would be used and hence only three fields ( Ez, Hx & Hy ) required for processing. As the thickness of the dielectric is small compared with the dimensions of the microstrip conductor, the Ez field can be assumed to be uniform beneath the strip while the microstrip struc-ture can be assumed to have magnetic walls.

Unfortunately, the model does not directly allow for fringing effects at edge discontinuities, but should give a reasonable response for loaded regions within the patch structure. However, by use of the $\varepsilon$ and $\sigma$ terms at the structure boundary, susceptive loading due to evanescent fields, and radiation can in some way be modelled - these values being derived from experimental observation. Fig. 4 shows the grid model used in the initial simulation runs.

For comparison with the simulation model, a rectangular microstrip patch antenna, 86.4 x 57.6 mm, was again used; though this time fed, via a 50 Ω microstrip transmission line, to a rough matching point for the second lowest order natural resonance. The input response was then recorded for a 200MHz region about this frequency.

The results from the practical work were compared with the simulation, and the model modified to give suitable results. Now it could be reasonably assured that edge fringing and coupling had been taken into account.

### Simulation and Experimental Results

The next stage involved shorting out areas of both the simulation model and microstrip antenna, and comparing results obtained. Fig. 5 shows the input impedance simulation results for

the model for two cases: (1) shorting at region m=8, n=12, and (2) shorting at regions m=8, n=12 and m=11, n=14. Results obtained by locating shorting pins in equivalent positions in the microstrip antenna are given in Fig. 6. Both sets of results have been adjusted to the impedance monitor point on the feed, Fig. 4.

Location of the first pin produced little effect, but did improve the antenna/feed match slightly and increased the resonant frequency by 2 MHz. Therefore, a second pin was added to cause a larger change in the input response. This time the match was made worse and the resonant frequency increased by a further 7 MHz.

Although the simulation model was originally tuned to give a good response for the unloaded antenna over approximately 200 MHz region around resonance, there was still a good correlation between the theoretical and experimental results for the loaded microstrip cases. The resonant frequencies obtained were only a few MHz adrift, while the Q of the experi-mental antenna was slightly higher than that obtained in the simulation. However, the results obtained certainly form a basis for further work in this area in order to achieve a more realistic model.

### CONCLUSION

A description has been given of a model for the analysis of loaded microstrip structures by a method of tuning a two-dimensional FDTD model. Initial results have shown that this method has proved suitable for analysis of the fields within microstrip antennas incorporating shorting pins, and is currently being evaluated for the electronically controlled reactively loaded probe. At the moment, good results have only been obtained for a limited frequency band around the desired resonant point. However, the model is currently being further developed to allow for a more thorough analysis.

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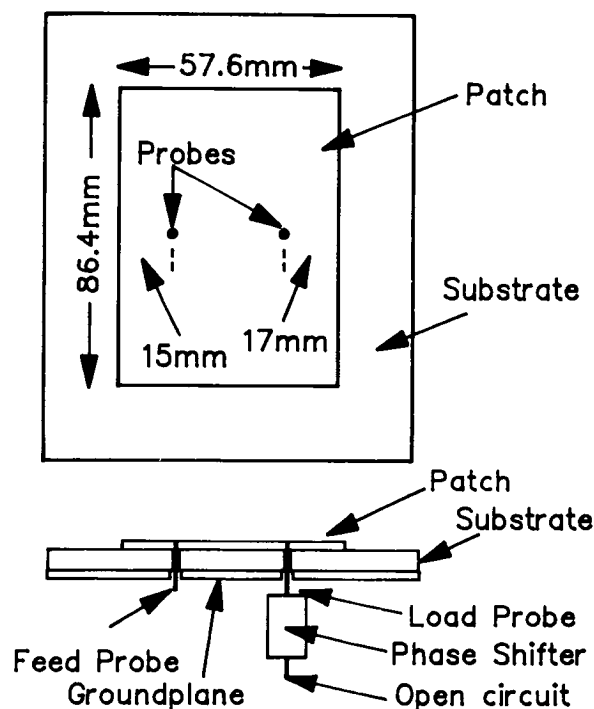
Fig. 1. Reactively Loaded Microstrip Patch Antenna.

Horizontal E Field Magnitude - solid
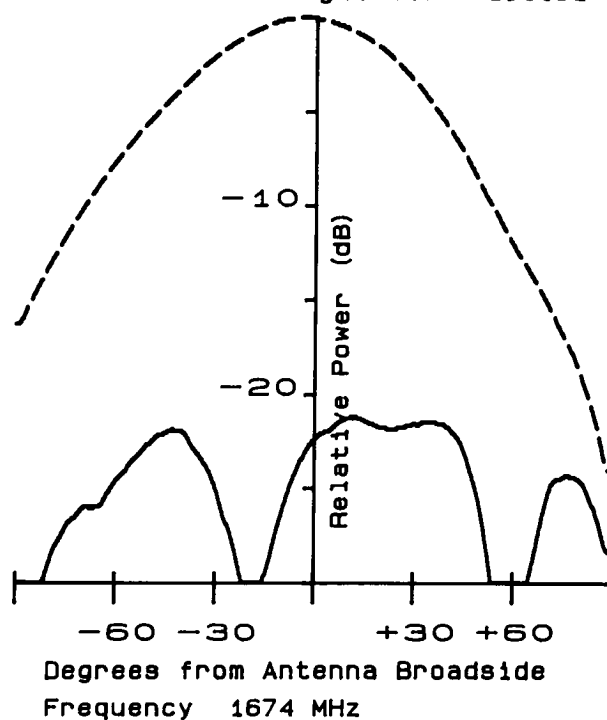Vertical E Field Magnitude - dotted



Degrees from Antenna Broadside
Frequency 1674 MHz

Fig. 2. Far—Field Radiation Plots ( phase shifter off )

Horizontal E Field Magnitude - solid
Vertical E Field Magnitude - dotted



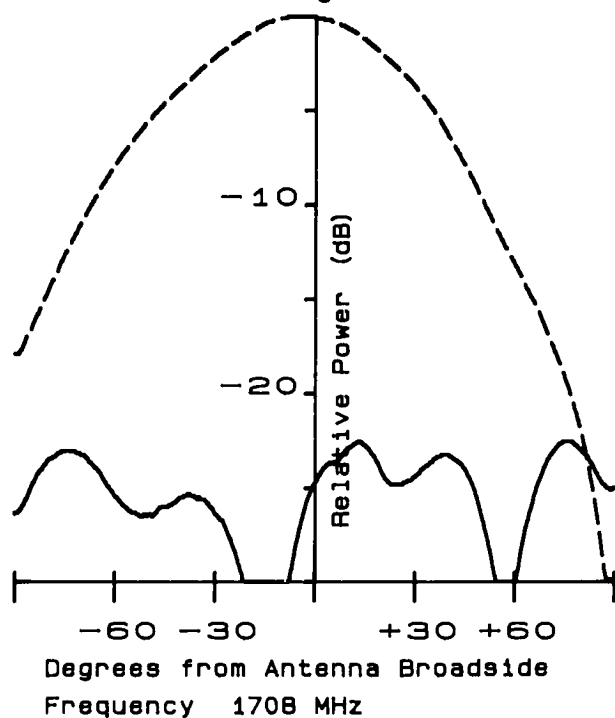Degrees from Antenna Broadside
Frequency 1708 MHz

**Fig. 3. Far—Field Radiation
Plots ( phase shifter on )**



**Fig. 4. Patch Simulation Grid
and Field Co—ordinates.**
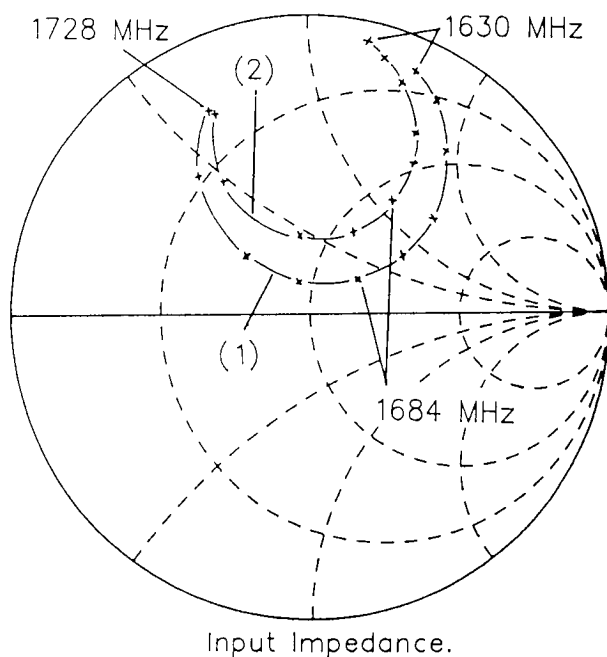


Input Impedance.

**Fig. 5. Simulation Results for
Coarse Grid Model with
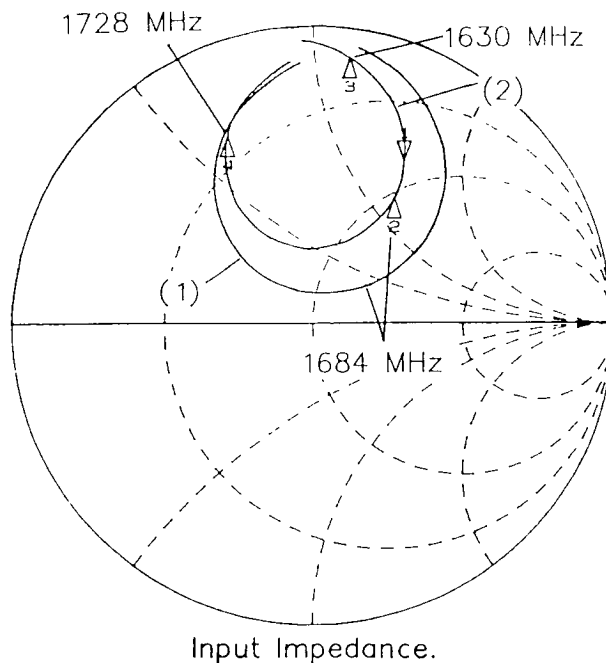shorted regions.**



Input Impedance.

**Fig. 6. Experimental Results for
Microstrip Antenna with
shorting pins.**